

SYSTEMS, METHODS, AND COMPUTER PROGRAM PRODUCTS FOR
PROVIDING TRAFFIC FREQUENCY DIVERSIFICATION IN A CELLULAR
COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates generally to the field of cellular communication systems, and, more particularly, to cellular communication systems that use time division multiple access (TDMA) technology, such as those based on the Telecommunication Industry Association (TIA)/Electronic Industries Association (EIA)/American National Standards Institute (ANSI) 136 standard or the global system for mobile communication (GSM) standard.

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Wireless communications systems are commonly used to provide voice and data communications to subscribers. For example, analog cellular radiotelephone systems have long been deployed successfully throughout the world. Digital cellular radiotelephone systems, such as those conforming to the North American TIA interim standard (IS) 54 and the European standard GSM have been in service since the early 10

1990's. More recently, a wide variety of wireless digital services have been introduced, which are broadly labeled as PCS (Personal Communications Services), and include advanced digital cellular systems conforming to standards such as ANSI-15

136 and IS-95, lower-power systems such as DECT (Digital Enhanced Cordless Telephone), and data communications services such as CDPD (Cellular Digital Packet Data). These and other systems are described in *The Mobile Communications Handbook*, edited by Gibson and published by CRC Press (1996).

FIG. 1 is a high-level block diagram of a conventional GSM network 20. The 20

GSM network includes a base station subsystem 22 that communicates with a mobile terminal 24 using a radio link protocol. The base station subsystem 22 may also

communicate with a Serving Generalized Packet Radio Service (GPRS) Support Node (SGSN) 26 and a Mobile Switching Center (MSC) 28. The SGSN 26 may access an external packet data network 32 via a Gateway GPRS Support Node (GGSN) 34. The MSC 28 typically functions as a conventional switching node in the Public Switched Telephone network (PSTN)/Integrated Services Data Network (ISDN) 36. The SGSN 26 and the MSC 28 may be coupled to each other and may also access a pair of databases known as the Home Location Register (HLR) 38 and the Visitor Location Register (VLR) 42.

The base station subsystem 22 may comprise a base station controller and one or more base transceiver stations. A base transceiver station contains the radio transceiver that defines an individual cell in the GSM network and communicates with mobile terminals in the cell using a radio-link protocol. The base station controller is generally used to manage resources for one or more base station transceivers. These resource management duties may include radio-channel setup, frequency hopping, and hand-offs of mobile terminals between cells.

GSM provides both circuit switched data services and packet switched data services. Packet switched data services are provided through a GSM protocol known as GPRS. The base station subsystem 22 may communicate with the SGSN 26 for packet switched and/or circuit switched data connections. Conversely, the base station subsystem 22 may communicate with the MSC 28 for voice connections.

The MSC 28 and the SGSN 26 may provide the functionality used to service the mobile terminal 24 along with other mobile terminals in the GSM network. In particular, the MSC 28 and SGSN 26 may provide registration, authentication, location updating, hand-offs, and call routing services to roaming subscribers. To provide these services, the MSC 28 and SGSN 26 may access information stored in the HLR 38 and the VLR 42 databases.

For example, the HLR 38 typically contains administrative information associated with subscriber's registered in the GSM network along with the current locations of the subscribers' mobile terminals. The location of a mobile terminal may be represented as the signaling address of the VLR 42 associated with the mobile terminal. The VLR 42 typically contains selected administrative information from the HLR 38 for mobile terminals that are currently located in the geographical region

controlled by the VLR 42. Accordingly, the MSC 28, SGSN 26, HLR 38, and VLR 42 may cooperate to provide call routing and roaming functionality for the GSM network.

As end-user services move towards mobile multimedia, a new technology, 5 known as Enhanced Data Rates for Global Evolution (EDGE), may be used in GSM networks to boost network capacity and increase data rates. EDGE may increase data rates for circuit switched connections via an Enhanced Circuit Switched Data (ECSD) mode and for packet switched connections via an Enhanced Generalized Packet Radio Service (EGPRS) mode up to three-fold. Moreover, because EDGE is built on the 10 existing GSM standard and uses the same TDMA frame structure, EDGE service may typically be introduced into a GSM network via a software/firmware retrofit of the base station subsystem 22 and introduction of EDGE compatible mobile terminals.

SUMMARY OF THE INVENTION

According to embodiments of the present invention, a mobile terminal and a 15 base station subsystem (*e.g.*, a base transceiver station and a base station controller) may communicate by assigning a primary or control frequency to the cell in which the mobile terminal is located and then using that control frequency to exchange control information between the mobile terminal and the base station subsystem. The 20 exchange of control information in the cell is constrained to the primary or control frequency. In addition, a plurality of traffic frequencies may be assigned to the cell and used to exchange traffic information between the mobile terminal and the base station subsystem using coordinated frequency hopping.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features of the present invention will be more readily understood from the following detailed description of specific embodiments thereof when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram that illustrates a conventional GSM cellular 30 network;

FIG. 2 is a high-level diagram of an exemplary cellular communication system that illustrates cellular communication systems, methods, and computer program products in accordance with the present invention;

FIG. 3 is a block diagram that illustrates a processor and memory that may be used in a mobile terminal shown in **FIG. 2** in accordance with an embodiment of the present invention;

5 **FIG. 4** is a block diagram that illustrates a processor and memory that may be used in a base transceiver station shown in **FIG. 2** in accordance with an embodiment of the present invention;

FIG. 5 is a block diagram that illustrates a processor and memory that may be used in a base station controller shown in **FIG. 2** in accordance with an embodiment of the present invention;

10 **FIG. 6** is a frequency distribution diagram that illustrates an exemplary bandwidth allocation in accordance with an embodiment of the present invention;

FIG. 7 is a block diagram that illustrates a cellular network in which the frequencies shown in **FIG. 6** have been assigned to respective cells in accordance with an embodiment of the present invention;

15 **FIGS. 8A - 8D** are frequency assignment charts based on time slot and frame for four cells shown in the cellular network of **FIG. 7** in accordance with an embodiment of the present invention;

FIG. 9 is a frequency distribution diagram that illustrates an exemplary bandwidth allocation in accordance with an embodiment of the present invention;

20 **FIG. 10** is a frequency distribution diagram that illustrates an exemplary bandwidth allocation in accordance with an embodiment of the present invention;

FIG. 11 is a block diagram that illustrates a cellular network in which the control frequencies shown in **FIG. 10** have been assigned to respective cells in accordance with an embodiment of the present invention;

25 **FIG. 12** is a block diagram of the cellular network of **FIG. 11** in which the traffic frequencies shown in **FIG. 10** have been assigned to respective cells in accordance with an embodiment of the present invention; and

FIGS. 13A - 13C are frequency assignment charts based on time slot and frame for three cells shown in the cellular network of **FIG. 12** in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular forms disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims. Like reference numbers signify like elements throughout the description of the figures.

The present invention is described herein in the context of a mobile terminal.

As used herein, the term "mobile terminal" may include a cellular radiotelephone with or without a multi-line display; a Personal Communications System (PCS) terminal that may combine a cellular radiotelephone with data processing, facsimile and data communications capabilities; a PDA that can include a radiotelephone, pager, Internet/intranet access, Web browser, organizer, calendar and/or a global positioning system (GPS) receiver; and a conventional laptop and/or palmtop receiver or other appliance that includes a radiotelephone transceiver. Mobile terminals may also be referred to as "pervasive computing" devices.

In addition, the present invention is described herein in the context of a GSM/EDGE cellular communication system. While the present invention may be particularly useful for improving the performance of GSM/EDGE cellular networks, it should be understood that the principles of the present invention may be applied to any cellular or wireless system that uses TDMA technology, which includes hybrid systems that combine code division multiple access (CDMA) technology and/or frequency division multiple access (FDMA) technology with TDMA. Accordingly, a mobile terminal, in accordance with the present invention, may be designed to communicate with a base station transceiver using the GSM standard, the ANSI-136 standard, or any other wireless communication standard that is based on TDMA.

The present invention may be embodied as cellular communication systems, methods, and/or computer program products. Accordingly, the present invention may be embodied in hardware and/or in software (including firmware, resident software, micro-code, etc.). Furthermore, the present invention may take the form of a computer program product on a computer-readable storage medium having computer-readable program code embodied in the

medium for use by or in connection with an instruction execution system. In the context of this document, a computer-readable or computer-readable medium may be any medium that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

5 The computer-readable or computer-readable medium may be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples (a nonexhaustive list) of the computer-readable medium would include the following: an electrical connection having one or more wires, a portable computer
10 diskette, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, and a portable compact disc read-only memory (CD-ROM). Note that the computer-readable or computer-readable medium could even be paper or another suitable medium upon which the program is printed, as the program can be electronically captured, via, for
15 instance, optical scanning of the paper or other medium, then compiled, interpreted, or otherwise processed in a suitable manner, if necessary, and then stored in a computer memory.

Referring now to **FIG. 2**, a mobile terminal **52** suitable for use with the present invention may include a keyboard/keypad **54**, a display **56**, a speaker **58**, a
20 microphone **62**, a transceiver **64**, and a memory **66** that communicate with a processor **68**. The transceiver **64** receives incoming radio frequency signals from a base transceiver station **72** and transmits outgoing radio frequency signals to the base transceiver station **72** via an antenna **74**. The transceiver typically comprises at least one frequency synthesizer **76** and may comprise a second frequency synthesizer **78** as
25 will be discussed in greater detail hereinafter. The radio frequency signals transmitted between the mobile terminal **52** and the base transceiver station **72** may comprise both traffic and control signals (e.g., paging signals/messages for incoming calls), which are used to establish and maintain communication with another party or destination. The foregoing components of the mobile terminal **52** may be included in many
30 conventional mobile terminals and their functionality is generally known to those skilled in the art.

The base transceiver station **72** contains the radio transceivers that define an individual cell in the cellular network and communicate with the mobile terminal **52**

and other mobile terminals in the cell using a radio-link protocol. The base transceiver station 72 also maintains a connection with a base station controller 82, which is generally used to manage resources for one or more base transceiver stations. These resource management duties may include radio-channel setup, frequency hopping, and hand-offs of mobile terminals between cells. Together, the base transceiver station 72 and the base station controller 82 comprise a base station subsystem. Finally, the base transceiver station 72 may maintain a communication link with a satellite communication system 84, such as the global positioning system (GPS), which may be used for purposes of timing and synchronization as will be discussed in greater detail hereinafter. It should be understood that a base transceiver station 72 facility (*i.e.*, tower) may contain multiple radio transceivers and directional antennas, which may be used to define multiple cells in a cellular network. As used herein, the base transceiver station 72 represents at least one radio transceiver that is assigned to a single cell.

FIG. 3 illustrates a processor 86 and memory 88, which may be used in the mobile terminal 52 of **FIG. 2**. The processor 86 communicates with the memory 88 via an address/data bus 92. The processor 86 may be, for example, a commercially available or custom microprocessor suitable for an embedded application. The memory 88 is representative of the overall hierarchy of memory devices containing the software and data used to implement the functionality of the mobile terminal 52. The memory 88 may include, but is not limited to, the following types of devices: cache, ROM, PROM, EPROM, EEPROM, flash, SRAM, and DRAM.

As shown in **FIG. 3**, the memory 88 may hold four major categories of software and data used in the mobile terminal 40: the operating system 94; the input/output (I/O) device drivers 96; the GSM/EGPRS protocol program module 98; and the frequency hopping program module 102. The I/O device drivers 96 typically include software routines accessed through the operating system 94 to communicate with devices such as the keyboard/keypad 54, display 56, speaker 58, microphone 62, and certain memory 88 components.

The GSM/EGPRS protocol program module 98 may comprise programs for implementing the GSM/EGPRS protocol stack on the mobile terminal 52. The frequency hopping program module 102 may comprise programs for processing a

frequency hopping sequence that is received from the base transceiver station 72 and programs for tuning the frequency synthesizers 76 and 78 to the frequencies defined in the hopping sequence at appropriate times to maintain communication with the base transceiver station 72.

5 **FIG. 4** illustrates a processor 104 and a memory 106, which may be used in the base transceiver station 72 of **FIG. 2**. The processor 104 communicates with the memory 106 via an address/data bus 108. The processor 104 may be, for example, a commercially available or custom microprocessor suitable for an embedded application. The memory 106 is representative of the overall hierarchy of memory
10 devices containing the software and data used to implement the functionality of the base transceiver station 72. The memory 106 may include, but is not limited to, the following types of devices: cache, ROM, PROM, EPROM, EEPROM, flash, SRAM, and DRAM.

15 As shown in **FIG. 4**, the memory 106 may hold three major categories of software and data used in the base transceiver station 72: the operating system 112; the GSM/EGPRS protocol program module 114; and the frequency hopping synchronization program module 116. The GSM/EGPRS protocol program module 114 may comprise programs for implementing the GSM/EGPRS protocol stack on the base transceiver station 72. The frequency hopping synchronization program module 20 116 may comprise programs for tuning the transceivers in the base transceiver station 72 to the frequencies defined in the hopping sequence. Moreover, the frequency hopping synchronization program module 116 may comprise programs for maintaining proper synchronization with other base transceiver stations in the GSM cellular network through communication with, for example, the GPS satellite 84.

25 **FIG. 5** illustrates a processor 118 and a memory 122, which may be used in the base station controller 82 of **FIG. 2**. The processor 118 communicates with the memory 122 via an address/data bus 124. The processor 118 may be, for example, a commercially available or custom microprocessor suitable for an embedded application. The memory 122 is representative of the overall hierarchy of memory
30 devices containing the software and data used to implement the functionality of the base station controller 82. The memory 122 may include, but is not limited to, the

following types of devices: cache, ROM, PROM, EPROM, EEPROM, flash, SRAM, and DRAM.

As shown in FIG. 5, the memory 122 may hold four major categories of software and data used in the base station controller 82: the operating system 126; the
5 GSM/EGPRS protocol program module 128; the radio resource management program module 132, and the frequency hopping pattern program module 134. The
GSM/EGPRS protocol program module 128 may comprise programs for
implementing the GSM/EGPRS protocol stack on the base station controller 82. The
radio resource management program module 132 may comprise programs for
10 managing radio resources for the base transceiver station 72 and any other base
transceiver stations under the control of the base station controller 82. Accordingly,
the radio resource management program module 132 may provide such functions as
radio-channel setup, frequency hopping, and hand-offs of mobile terminals between
cells. The frequency hopping pattern program module 134 may comprise programs
15 for maintaining frequency hopping patterns for cells under the control of the base
station controller 82 and for communicating these hopping patterns to mobile
terminals through the base transceiver stations associated with these cells.

Computer program code for carrying out operations of the respective program
modules associated with the mobile terminal 52, the base transceiver station 72, and
20 the base station controller 82 is preferably written in a high-level programming
language, such as C or C++, for development convenience. Nevertheless, some
modules or routines may be written in assembly language or even micro-code to
enhance performance and/or memory usage. While the frequency hopping
synchronization program module 116 is shown to reside on the base transceiver
25 station 72 and the frequency hopping pattern program module 134 is shown to reside
on the base station controller 82, program code from each of these modules may also
execute partly on the base transceiver station 72 and partly on the base station
controller 82 or entirely on either the base transceiver station 72 or the base station
controller 82.

30 As will be further appreciated by those skilled in the art, the functionality of
the frequency hopping program module 102, the frequency hopping synchronization
program module 116, and the frequency hopping pattern program module 134 may

also be implemented using discrete hardware components, a single application specific integrated circuit (ASIC), or a programmed digital signal processor or microcontroller.

As discussed hereinabove, EDGE technology may provide relatively poor
5 performance in the delivery of real-time services, such as voice. One factor that tends to degrade the performance of EDGE networks and other wireless communication networks is multi-path fading of the radio signals transmitted between the mobile terminals and the base transceiver stations. One type of multi-path fading is known as flat fading, which may arise from the interaction of a transmitted signal (the main ray) 10 with reflected versions of the transmitted signal that arrive concurrently at a receiver. Time dispersion, another type of fading, may arise from interaction of the main ray with time-delayed reflections of the main ray.

In accordance with the present invention, a code-word in an EDGE network may be encoded over a plurality of non-contiguous frequencies. In general, the fading 15 experienced on diverse, non-contiguous frequency bands is uncorrelated between the respective bands. Consequently, a code-word carried over a plurality of non-contiguous frequencies may be more likely to experience random, uncorrelated fading, which may improve the signal to noise ratio (SNR) of the signal and, as a result, improve network performance. The foregoing principles will be illustrated hereafter 20 by way of example with reference to an EDGE network. Recall, however, that the present invention may be used in any wireless or cellular network that uses TDMA technology.

An exemplary frequency distribution diagram for deploying EDGE service in 2.4 MHz of bandwidth is shown in **FIG. 6**. The frequency spectrum is divided into 25 twelve, 200 kHz sub-bands, which are respectively centered at frequencies **f₁** through **f₁₂**. A pair of guard bands provides separation between the EDGE deployment and other services using the neighboring frequency spectrum. It should be understood that the EDGE bandwidth may alternatively be divided into more than twelve sub-bands. In this case, each of the frequencies **f₁** through **f₁₂** would represent an equivalence 30 class of frequencies (*i.e.*, a plurality of frequencies that may be used interchangeably) rather than a single frequency.

The frequencies **f₁** through **f₁₂** are arranged into four groups of three contiguous frequencies as denoted by the Roman numerals **I** through **IV**. By selecting

a single frequency from each of the four groups, the primary frequencies may be assigned to cells in a GSM/EDGE cellular network using a 4/12 (*i.e.*, three groups of four frequencies) reuse pattern as shown in **FIG. 7**. Each cell in the network is labeled with a primary frequency and the Roman numeral corresponding to that 5 frequency's group assignment in **FIG. 6**. The three groups of four frequencies that are reused throughout the network are highlighted by three different background shade patterns.

The primary frequency assignment for each of the cells in the GSM/EDGE 10 cellular network may be engineered by the network operator and communicated to the base transceiver station **72** and the mobile terminal **52** via the base station controller **82**. In embodiments of the present invention, the primary frequency in each cell may also be called the control frequency because the Packet Broadcast Control Channel (PBCCH) and the Packet Common Control Channel (PCCCH) are always transmitted 15 on this frequency.

Recall, however, that, in accordance with the present invention, a frequency 20 hopping pattern may be defined for a cell, which is maintained in the frequency hopping pattern program module **134** in the base station controller **82**. These hopping patterns may be provided to the respective base transceiver stations, which are equipped with a frequency hopping synchronization program module **116** to transmit 25 the patterns to the mobile terminals. Preferably, the hopping pattern is transmitted using the PBCCH, which is defined by the primary/control frequency and one or more time slots. Thus, although control information is exchanged between the mobile terminal **52** and the base transceiver station **72** solely on the primary/control frequency assigned to the cell, traffic information may be exchanged between the mobile 30 terminal **52** and the base transceiver station **72** using a plurality of traffic frequencies as illustrated in **FIGS. 8A - 8D**.

FIGS. 8A - 8D are frequency assignment charts based on time slot and frame for four **Cells A** through **D** shown in the cellular network of **FIG. 7** and that illustrate exemplary frequency hopping patterns for the cells according to an embodiment of the 35 invention. First, note that for all four **Cells A** through **D**, time slot zero is always assigned to the primary/control frequency and serves as a control time slot for communication of the control channels PBCCH and PCCCH. The remaining time slots comprise traffic time slots and may be used for exchanging traffic information

between the mobile terminal 52 and the base transceiver station 72. Referring now to FIG. 8A, the mobile terminal 52 in **Cell A** uses frequency **f1** in frame zero, frequency **f4** in frame one, frequency **f7** in frame two, and frequency **f10** in frame three to exchange traffic information on time slots one through seven. The pattern is cyclical
5 as it repeats in frames four through seven. **Cells B** and **C** follow similar patterns with the four primary/control frequencies assigned to the four cells in a particular reuse group being rotated between the cells in cyclical fashion

Data is generally encoded over one Radio Link Control (RLC)/Medium Access Control (MAC) block and interleaved within the block. An RLC/MAC block
10 comprises four time slots spanning four frames as shown in FIGS. 8A - 8D. A code-word is, therefore, encoded over a plurality of non-contiguous traffic frequencies. Advantageously, using a different traffic frequency in each frame of an RLC/MAC block may ensure decorrelation of the fading seen in the four time slots and, further,
15 may reduce the variance of the instantaneous carrier to interference ratio (C/I) by bringing it closer to the average C/I of the channel. As a result, error performance may be sufficiently improved so that real-time services, such as voice, may be delivered over an EDGE network in a more efficient manner.

As shown in FIGS. 8A - 8D, the traffic frequency hopping pattern is cyclical; however, the hopping pattern may be random among the four primary/control
20 frequencies respectively assigned to **Cells A** through **D**. Furthermore, if the frequencies **f1** through **f12** represent equivalence classes of frequencies, the hopping pattern may be defined by making a random selection of a frequency belonging to the equivalence class that the primary frequency **fi**, $i = 1 - 12$, represents.

Referring again to FIG. 2, the base transceiver station 72 is preferably
25 equipped with two frequency synthesizers or two transceivers to allow for quick frequency transitions between adjacent time slots. For example, the frequency hopping synchronization program module 116 of the base transceiver station 72 may tune the spare transceiver or frequency synthesizer to the next frequency in the sequence before the time slot for that frequency arrives. When the time slot arrives,
30 the frequency hopping synchronization program module 116 may make the spare frequency synthesizer or transceiver active and switch the previously active frequency synthesizer or transceiver to a standby or spare mode to be tuned to the next frequency in the sequence. This may allow for rapid changes between frequencies as is

illustrated in **FIG. 8A** beginning at frame 1, time slot 7 through frame 2, time slot 1 where the base transceiver station 72 and the mobile terminal 52 change frequencies twice over a span of three time slots.

If the mobile terminal 52 is equipped with dual frequency synthesizers 76 and 5 78 as shown in **FIG. 2**, then the frequency hopping program module 102 may operate the two transceivers in active and standby mode as discussed in the foregoing with respect to the dual frequency synthesizers or transceivers in the base transceiver station 72. If, however, the mobile terminal 52 is not equipped with two frequency synthesizers (e.g., frequency synthesizer 78 is not included), then the frequency 10 hopping program module 102 and the frequency hopping synchronization program module 116 may coordinate the transitions between frequencies to ensure that at least one idle time slot is inserted between time slots associated with different frequencies as shown in **FIG. 8D** (a blank time slot is an idle time slot). These idle time slots may allow the frequency hopping program module 102 to tune the frequency synthesizer 15 76 to the next frequency in the hopping sequence.

The various base transceiver stations in the GSM/EDGE network are preferably synchronized to coordinate frequency hopping among the network cells. One possible approach to uniform synchronization is to use the frequency hopping synchronization program module 116 in the base transceiver station 72 to 20 communicate with the GPS satellite 84 to obtain a common time base by which frame and time slot boundaries may be defined.

Finally, it is envisioned that the frequency hopping synchronization program module 116 of the base transceiver station 72 in cooperation with the frequency hopping pattern program module 134 of the base station controller 82 may 25 periodically change the group identity of a cell. For example, as shown in **FIG. 7**, Cells A - D belong to a frequency reuse group that have been assigned primary/control frequencies f1, f4, f7, and f10. In accordance with the present invention, Cells A - D may be assigned a new group identity such that their primary/control frequencies are replaced with the primary/control frequencies from another frequency reuse group. 30 Thus, Cell A may have frequency f2 assigned as an alternative primary/control frequency, Cell B, may have frequency f5 assigned as an alternative primary/control frequency, Cell C may have frequency f8 assigned as an alternative primary/control

frequency, and **Cell D** may have frequency **f11** assigned as an alternative primary/control frequency. These new frequencies may then be used as part of a traffic frequency hopping pattern as discussed in the foregoing.

Referring now to **FIG. 9**, the exemplary EDGE deployment illustrated in **FIG. 6** may be modified to coexist with an auxiliary cellular communication system, such as ANSI-136, in the same bandwidth. In this embodiment, an ANSI-136 sub-band is interleaved between each of the four EDGE frequency groups identified in **FIG. 6**, such that the four frequencies assigned to a given frequency reuse group are non-contiguous and each separated by at least one of the ANSI-136 sub-bands.

Advantageously, this frequency distribution increases the total EDGE communication bandwidth with respect to the coherence bandwidth to increase the likelihood that fading between the EDGE carrier frequencies is uncorrelated. One drawback to this frequency distribution, however, is the consumption of additional frequency spectrum for guard bands to separate the EDGE sub-bands from the ANSI-136 sub-bands.

FIG. 10 is an exemplary frequency distribution diagram for deploying EDGE service in 2.4 MHz of bandwidth in accordance with an alternative embodiment of the present invention. In particular, this embodiment makes use of the EDGE Compact Air-Interface Mode that may provide greater spectral efficiencies through a lower spectral reuse pattern. EDGE Compact may be deployed in 600 kHz by isolating three carriers that are used in a 1/3 reuse pattern. In the **FIG. 10** example, frequencies **f1**, **f5**, and **f9** are selected for an EDGE Compact deployment. While these three frequencies are deployed in a 1/3 reuse pattern as shown in **FIG. 11**, the EDGE Compact standard takes advantage of the synchronization of the base transceiver stations serving the various cells in the GSM/EDGE network to create time-groups for the three EDGE Compact frequencies. In accordance with the EDGE Compact Standard, communication of control signaling (*i.e.*, PBCCH and PCCCH signaling) between a mobile terminal and a base transceiver station is only allowed during the time group assigned to the cell. Accordingly, when a first time group is active (*i.e.*, cells assigned to the first time group are allowed to communicate control information) cells belong to other time groups are idle (*i.e.*, no communication between the mobile terminals and the base transceiver stations). By using four time groups as represented by the four different shading patterns shown in **FIG. 11**, a 4/12 effective reuse may be obtained for communicating control information. Note, however, that the time groups

are not used in accordance with traffic channels, which means that traffic information is communicated using 1/3 frequency reuse of the three EDGE Compact frequencies with the condition that the traffic channels are not allowed to overlap in time with any of the control channels.

5 The remaining nine frequencies shown in **FIG. 10** may be deployed using 3/9 frequency reuse and used solely for traffic communication. The deployment of the nine traffic frequencies may be overlaid onto the EDGE Compact deployment of **FIG. 11** as shown in **FIG. 12** where the three reuse traffic frequency groups are outlined in bold.

10 **FIGS. 13A - 13C** are traffic frequency assignment charts based on time slot and frame for **Cells E** through **G** shown in the cellular network of **FIG. 12** and that illustrate exemplary frequency hopping patterns for the cells according to an embodiment of the invention. Essentially, the remaining nine frequencies that are not allocated to the EDGE Compact deployment may be deployed in a 3/9 reuse pattern analogous to the 4/12 reuse pattern discussed hereinabove with respect to **FIGS. 6 - 9**. Referring now to **FIG. 12**, because frequencies **f2**, **f6**, and **f10** are used solely for traffic, the frequency hopping program module **102** and the frequency hopping synchronization program module **116** may use a cyclical frequency hopping pattern by frame, which is provided by the frequency hopping pattern program module **134** in the base station controller **82**. The frequency hopping pattern for a given cell may even include frequencies outside of those defined for the cell's particular frequency reuse group (*i.e.*, outside of frequencies **f2**, **f6**, and **f10** for **Cells E**, **F**, and **G**). Care should be taken, however, when including frequencies in a frequency hopping pattern that are assigned to more distant cells as it generally more difficult to maintain synchronization between cells as the distance between the cells increases.

15 20 25

The **FIG. 12** embodiment may provide enhanced performance over a section of the EDGE frequency spectrum while providing improved spectral efficiency over another section of the EDGE frequency spectrum (*i.e.*, the spectrum allocated to the EDGE Compact deployment). Lower priority traffic may be assigned to the EDGE 30 Compact frequencies because of their lower frequency reuse factor while higher priority traffic may be assigned to the remaining frequencies.

As discussed hereinabove, the present invention stems from the realization that multi-path fading experienced on diverse, non-contiguous frequency bands may be

uncorrelated between the respective bands. Consequently, a code-word carried over a plurality of non-contiguous traffic frequencies may be more likely to experience random, uncorrelated fading, which may improve the signal to noise ratio (SNR) of the signal and, as a result, improve network performance.

5 In accordance with an aspect of the invention, control information may be exchanged during predefined control time slots while traffic information is exchanged during predefined traffic time slots. The predefined traffic time slots may be associated with the plurality of traffic frequencies so as to define a hopping pattern or sequence among the plurality of traffic frequencies. The hopping sequence may be
10 cyclical or random and may be transmitted to the mobile terminal using the control frequency. In particular, the hopping sequence may be transmitted to the mobile terminal using the primary packet broadcast control channel (PBCCH), which is defined by the control frequency and at least one of the control time slots.

15 For mobile terminals equipped with only a single frequency synthesizer, at least one idle time slot preferably separates traffic time slots that are associated with different traffic frequencies. Moreover, each of the predefined control time slots is preferably separated from traffic time slots that are associated with a frequency other than the control frequency by at least one idle time slot.

20 The traffic frequencies are preferably non-contiguous to allow for the encoding of a single code-word over at least a pair of non-contiguous traffic frequencies. For example, using a different traffic frequency in each frame of a radio link control (RLC)/medium access control (MAC) block, which, in a GSM/EDGE network, comprises four time slots spanning four frames, may ensure decorrelation of the fading seen in the four time slots and, further, may reduce the variance of the
25 instantaneous carrier to interference ratio (C/I) by bringing it closer to the average C/I of the channel. As a result, error performance may be sufficiently improved so that real-time services, such as voice, may be delivered over an EDGE network in a more efficient manner.

30 In accordance with yet another aspect of the invention, an auxiliary cellular communication system may coexist within the same bandwidth defined by the plurality of traffic frequencies. For example, sub-bands associated with an ANSI-136 cellular communication system may be interleaved between sub-bands associated with a GSM/EDGE cellular communication system. Such a frequency distribution may

increase the total EDGE communication bandwidth with respect to the coherence bandwidth to increase the likelihood that fading between the EDGE carrier frequencies is uncorrelated

In accordance with still another aspect of the invention, each of the plurality of traffic frequencies may be associated with an equivalence class of frequencies. A frequency may then be randomly selected from each of the plurality of equivalence classes and these randomly selected frequencies may then be used to communicate traffic information between the mobile terminal and the base station subsystem.

In accordance with yet another aspect of the invention, the plurality of traffic frequencies and the control frequency may be mutually exclusive. For example, the control frequency may be provided through an EDGE Compact deployment in which a plurality of control frequencies are deployed using a low frequency reuse factor (*e.g.*, 1/3 frequency reuse) for improved spectral efficiency. A plurality of traffic frequencies may then be overlaid on the control frequency deployment using a higher frequency reuse factor (*e.g.*, 3/9 frequency reuse). Traffic information may be communicated in each cell by way of frequency hopping among multiple traffic frequencies while control information is communicated over a single control frequency assigned to each cell.

In concluding the detailed description, it should be noted that many variations and modifications can be made to the preferred embodiments without substantially departing from the principles of the present invention. All such variations and modifications are intended to be included herein within the scope of the present invention, as set forth in the following claims.